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Spin Physics with COMPASS*

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On Behalf of the COMPASS Collaboration

The recently proposed COMPASS experiment at CERN attempts a measurement of the gluon polarisation with a precision of $\delta\Delta g/g \simeq 0.1$. The experiment uses open charm muoproduction to tag the photon-gluon fusion process.

One of the most urgent questions in understanding the nucleon's spin structure is the polarisation of gluons, $\Delta g/g$. A large value of Δg could explain the smallness of the contribution of the quark spins to the nucleon spin, $\Delta\Sigma$ [1, 2]. Hints for a large value of Δg in the order of $2-3 \hbar$ at $Q^2 = 10 \text{ GeV}^2$ come from a recent QCD analysis [3] of existing g_1 data. However, an unambiguous determination of Δg , can only be obtained from a process involving the gluon distribution in leading order. A particularly clean such process is open charm production via the photon-gluon fusion process, $\gamma g \rightarrow c\bar{c}$, shown in Fig. 1. Contributions from quark distributions can be neglected because there is no or only a small intrinsic charm quark content in the nucleon. The scale is set by the charm quark mass, $4m_c \simeq 10 \text{ GeV}^2$.

The main goal of the COMPASS experiment is the determination of $\Delta g/g$ from the cross section asymmetry for polarised open charm muoproduction from a fixed polarised target. The tagging of charm events is based on the identification of D^0 mesons via their $D \rightarrow K\pi$ decay channels. The experiment will also provide high statistics data for g_1 , semi-inclusive muon scattering, and the transversity structure function, h_1 . The layout of the apparatus is similar to that of the SMC experiment and parts of this setup will be used.

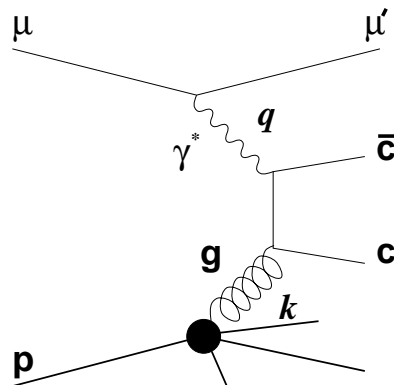


Figure 1: The photon-gluon fusion diagram.

For real or quasi-real photons the charm-production cross section via the photon-gluon fusion process can be written as

$$\sigma^{\gamma g \rightarrow c\bar{c}} = \sigma(\hat{s}) + \lambda_\gamma \lambda_g \Delta\sigma(\hat{s}), \quad (1)$$

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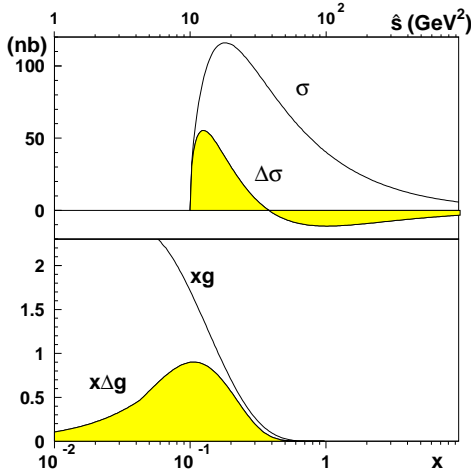


Figure 2: The photon-gluon cross sections σ and $\Delta\sigma$ as a function of \hat{s} (top) and xg and $x\Delta g$, as a function of $x = x_g$ (bottom).

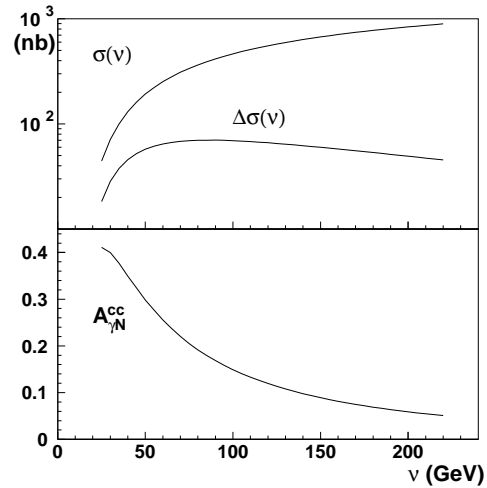


Figure 3: The photon-nucleon cross sections, σ and $\Delta\sigma$, (top) and the $A_{\gamma N}^{cc}$, (bottom) as a function of ν .

where $\hat{s} = (q + k)^2$ is the energy squared and $\lambda_{\gamma,g}$ are the helicities in the photon-gluon c.m. system. The spin-averaged and the spin-dependent part, $\sigma(\hat{s})$ and $\Delta\sigma(\hat{s})$, are known to next-to-leading and leading order [4, 5], respectively. Both terms, σ and $\Delta\sigma$, rise sharply at the threshold, $\hat{s} = 4m_c^2$, and $\Delta\sigma$ changes sign at about four times the threshold (Fig. 2). The photon-nucleon cross-section asymmetry, $A_{\gamma N}^{cc}$, for the process $\gamma N \rightarrow c\bar{c}$ is shown in Fig. 3. It is obtained by integrating the cross sections over the kinematically allowed range $x_g^{\min} \leq x_g \leq 1$

$$A_{\gamma N}^{cc}(\nu) = \frac{\Delta\sigma^{\gamma N \rightarrow c\bar{c}X}}{\sigma^{\gamma N \rightarrow c\bar{c}X}} = \frac{\int_{4m_c^2}^{2M\nu} d\hat{s} \Delta\sigma(\hat{s}) \Delta g(x_g, \hat{s})}{\int_{4m_c^2}^{2M\nu} d\hat{s} \sigma(\hat{s}) g(x_g, \hat{s})}. \quad (2)$$

Here $x_g = \hat{s}/2M\nu$ denotes the nucleon-momentum fraction carried by the gluon, which in this process is different from the kinematic variable, $x = Q^2/2M\nu$.

From coherence arguments [6] it is expected that the gluon polarisation behaves like $\Delta g(x)/g(x) \propto x$ for $x \rightarrow 0$. Such a behaviour is used in most parametrisations of the polarised gluon distribution function. Therefore, $\Delta g/g$ is expected to be large only at rather large values of x . For $x_g \geq 0.1$ the gluon polarisation can exceed 0.5. This value of x_g corresponds to a photon energy of order 50 GeV for which the \hat{s} and x_g axes in Fig. 2 correspond to each other. For the rate estimates we use the polarised gluon distribution of Ref. [7] (set B) shown in Fig. 2.

COMPASS is a fixed-target experiment similar to that of the SMC and uses a “Common Muon and Proton Apparatus for Structure and Spectroscopy”. Apart from the spin physics programme discussed here in part the proposal [8] also contains a spectroscopy programme with hadron beams. The experiment is statistics limited

even with the compared to the SMC experiment five times higher muon intensity of 2×10^8 muons per spill of 2.4 s every 14.4 s. The necessity to detect pions and kaons from the D decays in a wide angular range requires a two stage magnetic spectrometer with particle identification in both spectrometer stages. Downstream of the polarised target the new hadron stage of the spectrometer covers hadron angles in the range ± 200 mrad. Its large-aperture dipole magnet provides a bending power of 1 Tm. In the second stage of the spectrometer the scattered muon and fast hadrons are measured. It uses the present SMC spectrometer magnet. Particle identification will be performed by ring-imaging Cherenkov counters and by electromagnetic and hadronic calorimeters in each of the two spectrometer stages. The upstream and downstream RICH provide pion-kaon separation in the momentum range 3–65 GeV/c and 30–120 GeV/c, respectively. Existing lead-glass arrays will be used for the electromagnetic calorimeters. The hadronic calorimeters will in the muon programme mainly serve trigger purposes and tag deep-inelastic events. Both spectrometer stages end with a muon wall consisting of a hadron absorber followed by tracking chambers and trigger hodoscopes. The tracking in the beam region will be performed by scintillating fibre detectors. The large angles of the produced hadrons with respect to the incoming beam also require a new solenoid for polarised target with an opening of about ± 200 mrad matching that of the first spectrometer stage. As target materials lithium deuteride, ${}^6\text{LiD}$, for the deuteron and ammonia, NH_3 , for the proton are foreseen, polarised to 50 % and 85 %, respectively. The nuclear structure of ${}^6\text{LiD}$ is well described by the “alpha + deuteron” picture, which results in the favourable dilution factor of $f = 0.50$ compared to $f = 0.16$ for ammonia. The diameter of the two oppositely polarised 60 cm long target cells will be reduced to 3 cm in order to minimise the amount of material traversed. The nominal luminosity amounts to $\mathcal{L} = 5 \times 10^{32} \text{cm}^{-2} \text{s}^{-1}$. The minimum x_g value one wants to access determines the maximum photon energy, ν , needed. The muon energy should only be slightly larger than ν , in order to obtain a large average depolarisation factor, D . A muon energy of 100 GeV appears to be the optimal choice for $x_g \simeq 0.1$. The muon energy can be increased up to 200 GeV to explore smaller values of x_g .

For the kinematics of the COMPASS experiment we find in average 1.2 D^0 mesons per initial $c\bar{c}$ pair including D mesons from D^* decays. We concentrate on the two-body decays $\text{D}^0(c\bar{u}) \rightarrow \text{K}^- \pi^+$ and *c.c.* with branching ratios of 4 %. A major concern is the combinatorial background of kaon-pion pairs within the D mass window. The mass of the D meson will be reconstructed with a resolution of $\sigma_{M_D} \simeq 10$ MeV. In the range $25 < \nu < 85$ GeV the open charm production cross section amounts to 2 nb compared to 500 nb for ordinary photoproduction. Often the distance between the production and the decay vertex is used in charm experiments to clean up the kaon-pion sample. This technique cannot be applied in the COMPASS experiment, because this distance of a few mm cannot be resolved due to multiple scattering in the target. Kaons emitted at large angles, θ_K^* , in the D’s rest frame with respect to the D’s direction of flight in the laboratory frame have large transverse momenta. On the other hand, kaons from ordinary fragmentation have small transverse mo-

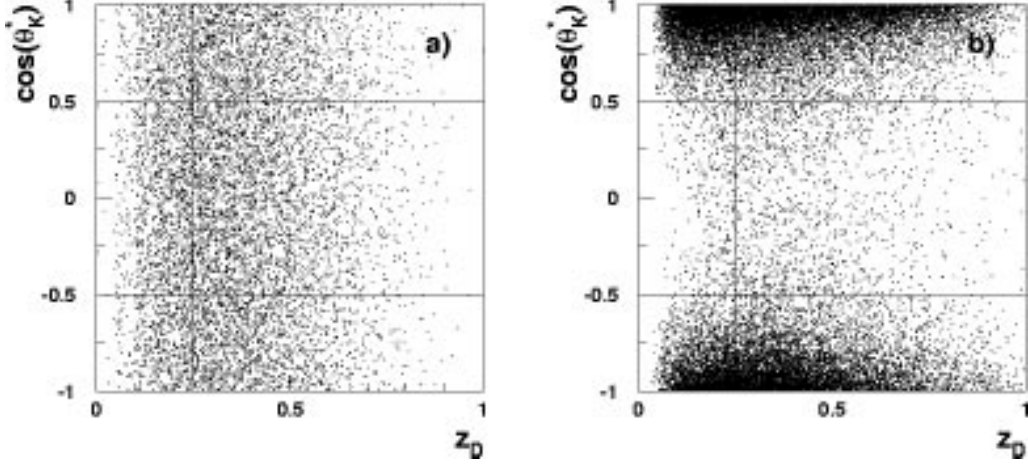


Figure 4: Monte-Carlo simulation: a) $D \rightarrow K\pi$ and b) combinatorial background versus z_D and $|\cos \theta_K^*|$. The lines indicates the cuts used in the rate estimates.

menta and thus dominantly mimic decays with small θ_K^* . The background rejection was studied in Monte Carlo simulations using the AROMA [9] and JETSET event generators for the photon-gluon fusion process and the background, respectively (Fig. 4). The best result is obtained with the requirements $|\cos \theta_K^*| \leq 0.5$ and $z_D = E_D/\nu \geq 0.25$, which improve the background-to-signal ratio by a factor 1750 to about $N^B/N^{cc} \simeq 3.8$ on the expense of loosing 65 % of the D mesons. For a running time of 2 1/2 years with 150 days/year and assuming a combined efficiency of 0.25 for the muon beam and the experimental apparatus the statistical error of the measured asymmetry is $\delta A_{\gamma N}^{cc} = 0.076$. Due to the higher figure of merit of the ${}^6\text{LiD}$ target a similar precision will already be reached after the first 1 1/2 years. The result can be improved using D^* tagging by the soft pion from the decay $D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow (K^- \pi^+) \pi_s^+$. Considering only the soft pions with momenta larger than 1 GeV/c and taking possible re-interaction in the target into account the statistical error of the asymmetry reduces to

$$\delta A_{\gamma N}^{cc} = 0.05 \quad \text{corresponding to} \quad \delta \frac{\Delta g}{g} = 0.14. \quad (3)$$

As in the inclusive case the muon-nucleon asymmetry is reduced from the virtual-photon asymmetry by the depolarisation factor, $A_{\mu N}^{cc} = D A_{\gamma N}^{cc}$ (Fig. 5). The sensitivity to $\Delta g/g$ peaks at $x_g = 0.14$ and covers the range $0.07 \leq x_g \leq 0.4$ (Fig. 6). Apart from the c.m. energy, \hat{s} , the asymmetry for the elementary photon-gluon fusion process, $\Delta\sigma(\hat{s}, \hat{\theta})/\sigma(\hat{s})$, also depends on on the c.m. angle, $\hat{\theta}$, between the photon-gluon axis and the $c\bar{c}$ axis. The sensitivity is larger for small angles, $\hat{\theta}$, corresponding in the laboratory frame to small transverse momenta, p_T . Rejecting D mesons with

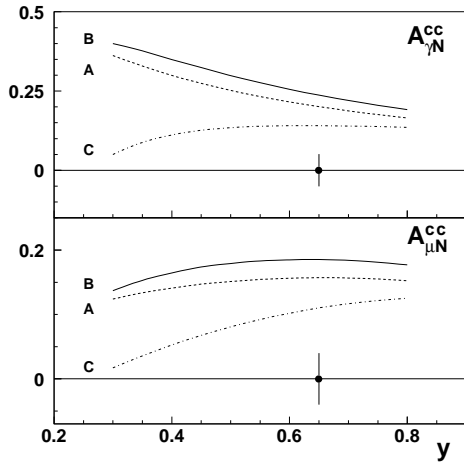


Figure 5: Photon-nucleon asymmetry (top), and muon-nucleon asymmetry (bottom), as a function of $y = \nu/E_\mu$ for the three gluon distributions of Ref. [7]. The data points indicate the projected precision of the COMPASS measurement.

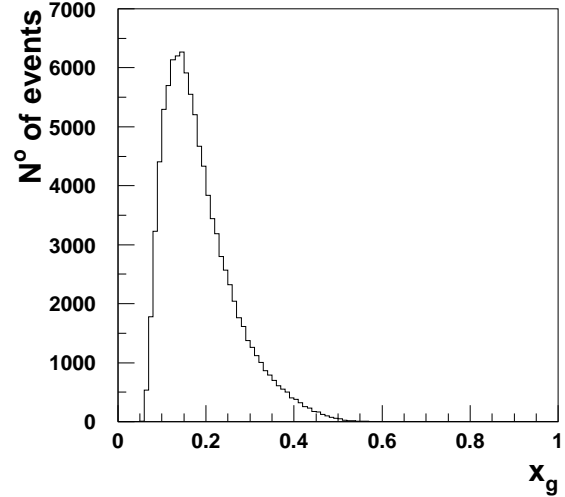


Figure 6: Number of accepted photon-gluon fusion events as a function of x_g for the range $35 \leq \nu \leq 85$ GeV.

$p_T > 1$ GeV/ c thus yields a larger analysing power leading to

$$\delta A_{\gamma N}^{cc} = 0.04 \quad \text{corresponding to} \quad \delta \frac{\Delta g}{g} = 0.11. \quad (4)$$

The three and four-body decay channels may further improve the precision, in particular if the D^* tagging can be applied. This is still under investigation.

Apart from the measurement of $\Delta g/g$ COMPASS offers a rich spin-physics programme at high Q^2 with a high luminosity including the transversity structure function h_1 , spin-flavour decomposition of the structure functions, and lambda polarisation in both the target and current fragmentation regions. The SPSLC has recommended the COMPASS experiment for approval. After commissioning in 1999 data taking could start in the year 2000.

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